Perceptual and prefrontal cortex haemodynamic responses to high-intensity interval exercise with decreasing and increasing work-intensity in adolescents

Adam A. Malik[1,2], Craig A. Williams[1], Kathryn L. Weston[3] and Alan R. Barker[1]

[1]Children's Health and Exercise Research Centre, Sport and Health Sciences, College of Life and Environmental Sciences, University of Exeter, Exeter, United Kingdom.

[2]Exercise and Sports Science Programme, School of Health Sciences, Universiti Sains Malaysia, Malaysia.

[3]School of Health and Social Care, Teesside University, Middlesbrough, United Kingdom.

Corresponding author:

Dr Alan R. Barker

Children's Health and Exercise Research Centre

Sport and Health Sciences

College of Life and Environmental Sciences

University of Exeter

St Luke's Campus

Exeter

EX1 2LU

Tel: 44 (0)1392 722766

Abstract

Objectives: Affect experienced during high-intensity interval exercise (HIIE) is dependent on work-intensity, but the influence of increasing (low-to-high (L-H)) or decreasing (high-to-low (H-L)) work-intensity during HIIE remains unclear in adolescents. The role of prefrontal cortex haemodynamics in mediating changes in affect during HIIE also remains unexplored in adolescents. We examined affect, enjoyment and cerebral haemodynamic responses to HIIE with increasing or decreasing work intensities in adolescents. **Methods**: Participants (N=16; 8 boys; age 12.5±0.8 years) performed, on separate days, HIIE cycling consisting of 8 x 1-minute work-intervals at 100%-to-70% ($HIIE_{H-L}$), 70%-to-100% ($HIIE_{L-H}$) or 85% ($HIIE_{CON}$) peak power separated by 75 seconds recovery. Affect, enjoyment and cerebral haemodynamics (oxygenation (ΔO_2Hb), deoxygenation (ΔHHb) and tissue oxygenation index (TOI)) were recorded before, during, and after all conditions. **Results**: Affect and enjoyment were lower during $HIIE_{H-L}$ compared to $HIIE_{L-H}$ and $HIIE_{CON}$ at work-intervals 1 to 3 (all $P<0.043$, ES>0.83) but were greater during $HIIE_{H-L}$ than $HIIE_{L-H}$ and $HIIE_{CON}$ at work-interval 8 (all $P<0.048$, ES>0.83). ΔO_2Hb was similar across conditions ($P=0.87$) but TOI and ΔHHb were significantly greater and lower, respectively during $HIIE_{H-L}$ compared to $HIIE_{L-H}$ and $HIIE_{CON}$ at work-interval 8 (all $P<0.039$, ES>0.40). Affect was correlated with TOI (all $r>0.92$) and ΔHHb (all $r>-0.73$) across conditions. **Conclusions**: $HIIE_{H-L}$ offers advancement to the $HIIE_{CON}$ and $HIIE_{L-H}$ which bring significant greater affect and enjoyment toward the end HIIE work-interval, implicating the feasibility and adoption of this protocol for health promotion in youth. Also, changes in prefrontal cortex haemodynamics are associated with the affect during HIIE.

Key Words: Affective valence, work interval, exercise prescription, prefrontal cortex oxygenation, youth.

1.0 INTRODUCTION

High-intensity interval exercise (HIIE) has been shown to be a potent strategy to enhance cardiometabolic health and cardiorespiratory fitness in adolescents (Bond, Weston, Williams, & Barker, 2017; Costigan et al., 2015). The adoption of HIIE to promote health benefits, however, has been disputed with some arguing that HIIE will generate negative affect (feelings of displeasure) and greater physiological (e.g. increased in heart rate (HR)) and exertional stress (e.g. increased rating of perceived exertion (RPE)), thus leading to poor implementation and maintenance in future sessions (Biddle & Batterham, 2015). Consequently, the effectiveness of HIIE protocol as a health strategy in youth is unclear.

The dual mode theory (DMT) provides a theoretical framework that integrates psychological/cognitive factors (e.g. self-efficacy) and physiological/interoceptive factors to explain the relationship between exercise intensity and affect responses (Ekkekakis, Hall, & Petruzzello, 2005). The DMT postulates that the dominant cognitive factor during exercise in the heavy exercise intensity domain (i.e. exercise performed above the ventilatory threshold (VT)) leads to large inter-individual variability, with some individuals perceiving the intensity as pleasurable, while others find it unpleasant (Rose & Parfitt, 2010). In contrast, physiological factors associated with metabolic strain (i.e. an increase in HR) dominate during exercise in the severe exercise intensity domain (exercise performed above the respiratory compensation point (RCP)). During the severe exercise intensity domain, the continuation of metabolic rate requires increased contributions of anaerobic sources and physiological steady state cannot be sustained, which leads to prominent feelings of displeasure (Ekkekakis et al., 2005). HIIE protocols are typically associated with a single work intensity that spans the heavy or severe exercise intensity domains (e.g. 70% to 100% of peak power, Bond et al., 2017). This reinforces the need to evaluate both psychological and physiological factors in research exploring HIIE as an effective health strategy in youth.

There are data in youth demonstrating that high-intensity exercise evokes prominent feelings of displeasure to support the DMT in youth. These observations were made during incremental exhaustive exercise and continuous exercise (Benjamin et al., 2012; Stych & Parfitt, 2011), which may not apply to HIIE involving brief bursts of high-intensity exercise separated by periods of low-intensity recovery exercise. Indeed, recent work has shown that pleasurable feelings are observed in 85% of participants during a commonly used HIIE protocol (i.e. 8 x 1 min performed at 90% peak power) in youth (Malik et al., 2018). The HIIE protocol also facilitated higher post-exercise enjoyment and preference compared to moderate-intensity continuous or interval exercise (Malik et al., 2017; 2018). The aforementioned studies are limited, however in terms of a single and constant work rate used to prescribe the HIIE protocol. Currently, no study has evaluated the effect of decreasing (high-to-low (H-L)) or increasing (low-to-high (L-H)) the work intensity during HIIE on the affective responses in adolescents. Zenko, Ekkekakis, and Ariely (2016) recently reported that continuous exercise of H-L intensity resulted in more pleasurable feelings towards the end of an exercise bout when compared to L-H intensity. This report suggests that prescribing HIIE using H-L work intensities (e.g. decreasing from 100% to 70% peak power) could improve affect experienced during exercise. Elucidating this information is important, as HIIE protocols that are capable of attenuating unpleasant feelings during exercise could encourage future attitudes towards PA behaviour in adolescents (Schneider, Dunn, & Cooper, 2009).

Previous research has shown HR and RPE to be elevated during HIIE and inversely correlated with the affective response in youth (Malik et al., 2018), suggesting that the decline in affect during HIIE may be related to the influence of physiological factors. The DMT predicts that the influence of physiological factors may hinder the ability of the prefrontal cortex (PFC) to control cognitive and affect processes, resulting in more negative affect (Ekkekakis & Acevedo, 2006). Reduced PFC activity occurs due to shifts in the metabolic resources (e.g. oxygen delivery) to the subcortical areas of the brain, driven by the intensified sensory body input (e.g. increased HR and RPE). It has been proposed that lower neural activation in the PFC is associated with a reduced (or plateau) cerebral oxygenation (ΔO_2Hb) in the presence of increased cerebral deoxygenation (ΔHHb) (Ekkekakis & Acevedo, 2006). Tempest, Eston, and Parfitt (2014) measured ΔO_2Hb in the PFC during an incremental test to exhaustion using near-infrared spectroscopy (NIRS), and found that changes in ΔO_2Hb were negatively correlated with changes in affect in healthy adult individuals. This observation suggests a potential mechanistic link between affect and the PFC during exercise. Whether the changes in affect evaluation during HIIE are related to PFC haemodynamics in youth, however, is currently unknown.

The purpose of this study is to examine the changes in affect, enjoyment and PFC haemodynamics (i.e. cerebral ΔO_2Hb, ΔHHb, and tissue oxygenation index (TOI)) in adolescents duringH-L (100% to 70% of peak power; $HIIE_{H-L}$), L-H (70% to 100% of peak power; $HIIE_{L-H}$) and constant (85% peak power; $HIIE_{CON}$) HIIE work intervals. We hypothesised that $HIIE_{H-L}$ would elicit more positive affect (i.e. more pleasurable) and an elevated cerebral oxygenation towards the end of the exercise bout compared to $HIIE_{L-H}$ and $HIIE_{CON}$.

2.0 METHODS

2.1 Participants

Sixteen adolescents (8 boys), aged 11 to 13 years old, volunteered to participate in the study. Prior to the recruitment, a brief explanation about this project was given to approximately 60 pupils during a school assembly. A total of 24 information packs (participant information sheet, health screening form, participant assent and parent consent forms) were taken by the pupils and sixteen were returned for participation in the study. The size of the sample was based on the ability to detect a medium to large effect in the affective responses using previous published data in youth (Malik et al., 2018). Based on 3 (condition) by 8 (interval) repeated measures ANOVA with an alpha of 0.05 and power of 0.8, a sample size of 9 or 18 participants to detect a moderate and large effect was indicated, respectively. Exclusion criteria included the inability to understand the study procedures, musculoskeletal injury especially to lower limbs which prevents participants from cycling, the presence of any condition or infection which could alter mood and exercise performance. The study procedures were granted by the Sport and Health Sciences Ethics Committee (170712/B/02), University of Exeter. Written assent from the participants and written informed consent from the parent/guardian were obtained.

2.2 Experimental overview

This study required four laboratory sessions which took place in a satellite laboratory in the school, separated by a minimum two-day rest period (mean = 5, SD = 2 days), and incorporated a within-measures design. The first visit was to measure anthropometric variables, determine cardiorespiratory fitness and familiarise participants with the measurement scales. This was followed by three experimental visits each involving a different HIIE work-interval protocol, the order of which was counterbalanced to control for an order or learning effect. Each of the participants was assigned to perform the exercise test at the same time of the day between the hours of 08:30 to 13:00. All exercise tests and HIIE protocols were performed using an electronically braked cycle ergometer (Lode Corival Pediatric, Groningen, The Netherlands).

2.2.1 Anthropometric, maturation and physical activity measures Stature and body mass were quantified to the nearest 0.01 m and 0.1 kg using standard procedures. Body mass index (BMI) was calculated as body mass (kg) divided by stature (m) squared. Age and sex specific BMI cut-points for overweight and obesity status were determined (Cole et al., 2000)). Percentage body fat was estimated using triceps and subscapular skinfolds to the nearest 0.2 mm (Harpenden callipers, Holtain Ltd, Crymych, UK) according to sex and maturation specific equations (Slaughter et al., 1988). The ratio standard method to scale for body mass was used to define low cardiorespiratory fitness as indicative of increased cardiometabolic risk based on age and sex specific aerobic fitness cut-offs in youth (Adegboye et al., 2011). Finally, maturation (somatic) offset from the age at peak height velocity was determined from participant age and stature using the modified equation of Moore et al. (2015). Earlier maturers participants were defined as the offset score <-1 year, typical matures participants were defined as the offset score between -1 to 1 year and late maturers were defined as the offset score >+1 year.

Following completion of the HIIE protocols, participants wore an accelerometer (GENEActiv, GENEA, UK) on their non-dominant wrist for seven days. The accelerometer was set to record at 100 Hz. Participants' data were used if they had recorded ≥10 hours/day of wear time for at least three week days and one weekend day (Riddoch et al., 2007). Data were analysed at 1 s epoch intervals to establish time spent in moderate and vigorous intensity physical activity using a cut-off point of ≥1140 counts per minute, which was previously validated in youth (Phillips et al., 2013).

2.2.2 Cardiorespiratory fitness Participants were familiarised to exercise on the cycle ergometer before completing a ramp test to establish maximal oxygen uptake ($\dot{V}O_{2max}$) and the VT (Barker et al., 2011). Participants began a warm-up of unloaded cycling for 3 min, followed by 15 W increments every 1 min until volitional exhaustion, before a 5 min cool down at 25 W. Participants cycling at a constant cadence between 75-85 rpm with exhaustion was defined as a drop in cadence below 60 rpm for 5 consecutive seconds despite strong verbal encouragement.

2.2.3 HIIE protocols Participants completed three different HIIE protocols consisting: 1) 2 x 1 min work intervals performed at 100%, 90%, 80% and 70% peak power (total of 8 work intervals), interspersed with 75 s recovery at 20 W ($HIIE_{H-L}$); 2) 2 x 1 min work intervals performed at 70%, 80%, 90% and 100% peak power (total of 8 work intervals), interspersed with 75 s recovery at 20 W ($HIIE_{L-H}$); and 3) 8 x 1 min work intervals performed at 85% peak power, interspersed with 75 s recovery at 20 W ($HIIE_{CON}$). A 3 min warm-up and a 2 min cool down was provided before and after each HIIE condition. The $HIIE_{CON}$ protocol was used as the 'control' condition, as this is a common protocol for delivery of HIIE in youth (Bond et al., 2017). The HIIE protocols were matched for exercise duration (i.e. 22 min 15 s), duration of the work and recovery intervals, and total (external) work performed.

2.3 Experimental Measures

2.3.1 Gas exchange and heart rate. Expired gas exchange and ventilation variables during the cardiorespiratory fitness test and HIIE protocols were measured using a calibrated metabolic cart (Cortex Metalyzer III B, Leipzig, Germany). HR responses were recorded continuously using a telemetry system (Polar Electro, Kempele, Finland). Both gas exchange and HR data were subsequently averaged over 10 s intervals. The VT was determined from the incremental test data using the ventilatory equivalents for carbon dioxide production ($\dot{V}CO_2$) and $\dot{V}O_2$. $\dot{V}O_{2max}$ was determined as the highest 10 s average in $\dot{V}O_2$ elicited either during the incremental test. Maximal HR (HR_{max}) was taken as the highest HR achieved during the ramp test. A cut-off point of ≥90 % HR_{max} was used as the criterion for compliance to the HIIE protocol (Malik et al., 2017a; Taylor at al., 2015).

2.3.2 Affective responses. Affective valence (pleasure/displeasure) was measured using the feeling scale (FS; Hardy & Rejeski, 1989) in line with previous work in adolescents (Benjamin et al., 2012; Malik et al., 2017a & b; Stych & Parfitt, 2011). Participants were asked to how they currently feel on an 11-point bipolar scale ranging from "Very Good" (+5) to "Very Bad" (-5). ΔFS represent the change in the affective response from work interval 1 to the work interval 8 across all HIIE conditions. Activation levels were measured using the felt arousal scale (FAS; Svebak & Murgatroyd, 1985). The FAS is a single-item measure of perceived activation, with participants asked to rate themselves on a 6-point scale ranging from 1 'low arousal' to 6 'high arousal'. Van Landyut et al. (2000) report that FS and FAS exhibited correlations ranging from 0.41 to 0.59 and 0.47 to 0.65, respectively, with the Affect Grid (Russell, Weiss, & Mendelsohn, 1989), indicative of convergent validity with similar established measures. Affective responses were also assessed from the perspective of the circumplex model (Russell et al., 1989), using a combination of FS and FAS scales.

2.3.3 Perceived enjoyment. Participants rated their enjoyment during the HIIE conditions to the statement "Use the following scale to indicate how much you are enjoying this exercise session" on a 7-point (i.e. "Not at all" at 1 to "Extremely" at 7) exercise enjoyment scale (EES; Stanley & Cumming, 2010). Stanley et al. (2009) report that EES exhibited correlations ranging from 0.41 to 0.49 with the FS, indicative of convergent validity with similar established measures. Post-exercise enjoyment was measured using the modified physical activity enjoyment scale (PACES), which is validated for use in adolescents (Motl et al., 2001). The PACES includes 16 items that are rated on a 5-point bipolar scale (score 1 = "strongly disagree" to score 5 = "strongly agree").

2.3.4 Rating of perceived exertion. RPE was assessed using the 0–10 Pictorial Children's OMNI scale (Robertson et al., 2000). Participants respond to the statement "How tired does your body feel during exercise" via a 0-10 point Likert item ranging from 0 (not tired at all) to 10 (very, very tired).

2.3.5 Measurement time points. The measurements scales (i.e. FS, FAS, EES, RPE and PACES) were administered before (i.e. 5 min before and warm-up), during HIIE work and recovery intervals, and after (i.e. immediately after and 20 min after) all HIIE conditions similar to the previous work in youth (Malik et al., 2017b). The same verbal instructions for using all the scales were given to all participants before undertaking the exercise protocols.

2.3.6 Cerebral hemodynamics. Cerebral hemodynamics were measured non-invasively using near infrared spectroscopy (NIRS; NIRO 200 Hamamatsu Photonics, Hamamatsu, Japan). The emitter and detector were encased in a rubber holder with a separation distance of 4 cm. Age-specific differential pathlength factors were calculated using the modified Beer-Lambert equation to provide a measure of the concentration changes (micromolar; mM) in cerebral oxygenation (ΔO_2Hb), cerebral deoxygenation (ΔHHb) and tissue oxygenation index (TOI) (Duncan et al., 1996). The probes were placed over the left hemisphere (dorsolateral prefrontal cortex areas; midpoint between Fp1-F3, of the international 10-20 system for EEG electrode placement) in line with previous studies in youth (e.g. Ganesan et al., 2016; Luszczyk et al., 2011). The probes were secured to the skin using a double adhesive sticker. An elastic black bandage was placed over the holders around the forehead. A 30 s baseline measure of cerebral hemodynamics was recorded before all HIIE conditions. Baseline measures were subtracted from the data extracted during exercise. Therefore, ΔO_2Hb and ΔHHb represent the change (from baseline) in the hemodynamic response at selected points during exercise. The TOI represents a measure of tissue oxygen saturation (the ratio of O_2Hb to total Hb); therefore, adjustments for baseline were not required. These variables were time aligned with the gas exchange data obtained during each work and recovery interval and 10-s averages were taken at the end of the work and recovery intervals for further analysis.

2.4 Statistical analyses

All statistical analyses were conducted using SPSS (SPSS 24.0; IBM Corporation, Armonk, NY, USA). The Shapiro-Wilks test was used to test normality of distribution for the dependent variables. Descriptive characteristics (mean ± standard deviation) between boys and girls were analysed using independent samples t-tests. Data were analysed using a mixed model analysis of variance (ANOVA) to examine differences in affect, enjoyment, PFC hemodynamics, RPE, and cardiorespiratory responses between HIIE protocols over time (e.g. the work and recovery intervals) and experimental orders (prescribed first, second or third). As the inclusion of sex into the ANOVA model did not reveal a significant interaction effect for all outcomes, data were subsequently pooled for analysis. A series of one-way repeated measure ANOVAs were also conducted to examine the magnitude of changes from baseline across the work interval in affect responses within each HIIE protocol. In the event of significant effects (P<0.05), follow-up Bonferroni post hoc test were conducted to examine the location of mean differences. The magnitude of mean differences was interpreted using effect size (ES) (Cohen, 1988), where an ES of 0.20 was considered to be a small change between means, and 0.50 and 0.80 interpreted as a moderate and large change, respectively. Pearson's product-moment correlation coefficient was used to examine the relationships between affect responses with PFC hemodynamics and post-exercise enjoyment.

3.0 RESULTS

The participants' descriptive characteristics are presented in Table 1. Fourteen participants (seven boys) were deemed to have a low level of fitness indicative of increased cardiometabolic risk. One girl was categorised as being overweight. A total of four boys were categorised as a late maturers (<-1 of maturation offset) and two girls were categorised as an early maturers (>+1 of maturation offset). The remaining nine participants were categorised as typical maturers. A total of two boys and one girl were achieving the recommended guideline of 60 min of MVPA per day. The remaining 13 participants were not achieving the MVPA guideline. The power output for the HIIE conditions was as follow: 70% peak power = 84 ± 12 W, 80% peak power = 96 ± 14 W, 85% peak power = 102 ± 15 W, 90% peak power = 108 ± 16 W and 100% peak power = 120 ± 17 W. All conditions exhibited the same total work performed (65.4 ± 7.3 kJ). All participants successfully completed the HIIE conditions with no adverse events. The inclusion of experimental orders into the ANOVA model did not reveal a significant interaction effect for all outcomes (all P>0.33), showing that the counterbalance order did not influence the perceptual and physiological responses in this present study.

3.1 Cardiorespiratory responses Cardiorespiratory data from the exercise conditions for boys and girls are presented in Table 2. There was a significant condition by interval number interaction for HR (all *P*<0.01). $HIIE_{L-H}$ and $HIIE_{CON}$ elicited higher peak HR to $HIIE_{H-L}$ (all *P*<0.05). Also, $HIIE_{H-L}$ generated a lower HR response (both absolute and relative) compared to $HIIE_{CON}$ and $HIIE_{L-H}$ at work interval 8 (162 ± 6 (86 %HR_{max}) vs. 179 ± 4 (95 % HR_{max}), ES=3.33; 162 ± 6 vs. 183 ± 4 (97 % HR_{max}), ES=3.62, respectively). All participants (n=16, 100% of participants) reached the cut-off point of ≥90% HR_{max} during $HIIE_{L-H}$ and 15 (93%) and 12 (75%) participants reached the cut-off during $HIIE_{CON}$ and $HIIE_{H-L}$, respectively.

3.2 Affective responses FS responses during the HIIE work intervals are illustrated in Figure 1A. FS showed a significant condition by interval number interaction effect (*P*<0.01). FS was significantly lower during $HIIE_{H-L}$ than $HIIE_{L-H}$ (all *P*<0.001, ES=1.32 to 1.75) and $HIIE_{CON}$ (all *P*<0.008, ES=0.96 to 1.17) at work intervals 1 to 3. However, FS was significantly higher during $HIIE_{H-L}$ than $HIIE_{L-H}$ at work intervals 7 and 8 (*P*<0.001, ES=1.46 to 1.67) and $HIIE_{CON}$ at work interval 8 (*P*=0.049, ES=0.83). FS was also significantly greater during $HIIE_{CON}$ than $HIIE_{L-H}$ at work intervals 7 and 8 (all *P*<0.04, ES=0.70 to 1.74). ΔFS was significantly lower in $HIIE_{H-L}$ than $HIIE_{CON}$ (*P*<0.01, 0.4 ± 0.9 vs. 2.0 ± 1.5, ES=1.29) and $HIIE_{L-H}$ (*P*<0.01, 0.4 ± 0.9 vs. 3.2 ± 1.3, ES= 2.50). ΔFS was also significantly lower in $HIIE_{CON}$ than $HIIE_{L-H}$ (*P*=0.03, 2.0 ± 1.5 vs. 3.2 ± 1.3, ES= 0.85). The decline in FS from baseline (5 min pre) was significant from work intervals 3 to 8 (all *P*<0.03; ES=0.92 to 2.07) and from work interval 5 to 8 (all *P*<0.005; ES=1.66 to 3.09) in $HIIE_{CON}$ and $HIIE_{L-H}$, respectively. In contrast, the decline in FS was only significant from baseline up to work-interval 6 during $HIIE_{H-L}$ (all *P*<0.014; ES=1.29 to 1.47). FS remained positive at work interval 8 during $HIIE_{H-L}$ (2.2 ± 1.3 on FS score) in all participants (n =16, 100%), in 15 participants (93%) during $HIIE_{CON}$ (1.1 ± 1.3 on FS score) and in 12 participants (75%) during $HIIE_{L-H}$ (0.3 ± 1.0 on FS score).

FAS responses during the HIIE work intervals are illustrated in Figure 1C. FAS showed a significant condition by interval number interaction (P<0.01). FAS was significantly greater during $HIIE_{H-L}$ than $HIIE_{L-H}$ at work-intervals 1 to 4 (all P<0.001; ES = 0.91 to 1.78), but significantly lower during $HIIE_{H-L}$ than $HIIE_{L-H}$ at work-intervals 7 and 8 (all P<0.01; ES = 2.08 to 1.59). FAS was also significantly higher during $HIIE_{H-L}$ than $HIIE_{CON}$ at work-intervals 1 and 2 (all P<0.006; ES= 1.29 to 1.45), but significantly lower during $HIIE_{H-L}$ than $HIIE_{CON}$ at work-interval 8 (P= 0.002; ES = 1.46).

Affective responses (valence and activation) during the work and recovery intervals for the HIIE protocols were plotted onto a circumplex model (Figures 2). There was a shift from the unactivated/pleasant to the activated/pleasant quadrant during the work intervals for all conditions, but during $HIIE_{H-L}$ affective responses shifted back to the unactivated/pleasant quadrant at work interval 8. The affective responses remained in the unactivated/pleasant quadrant for HIIE recovery intervals in all conditions.

3.3 Exercise enjoyment responses Enjoyment responses during the HIIE work intervals are illustrated in Figure 1C. EES showed a significant condition by interval number interaction (P<0.01). EES was significantly lower during $HIIE_{H-L}$ than $HIIE_{CON}$ and $HIIE_{L-H}$ at work intervals 1 and 2 (all P<0.043; ES>0.89), but significantly greater than $HIIE_{L-H}$ at work-interval 8 (P=0.01; ES=1.82). EES was also significantly greater during $HIIE_{CON}$ than $HIIE_{L-H}$ at work-interval 8 (P=0.017; ES= 1.26).

There was no condition by time interaction (P=0.58) or effect of condition (P=0.62), but there was a main effect of time (P<0.001) for PACES. PACES was significantly higher 20-min post compared to immediately after HIIE ($HIIE_{H-L}$, 76 ± 2 vs. 74 ± 3, P=0.02, ES=0.67; $HIIE_{CON}$, 76 ± 3 vs. 73 ± 2, P=0.002, ES=1.18; $HIIE_{L-H}$, 75 ± 3 vs. 73 ± 3, P=0.049, ES=0.67, respectively). There was a positive correlation between the FS at work-interval 8 and PACES score immediately after and 20 min post $HIIE_{H-L}$ (P=0.031, r=0.55; P=0.041, r=0.58, respectively) and $HIIE_{CON}$ (P=0.036, r=0.65; P=0.046, r=0.63, respectively), but not in $HIIE_{L-H}$ (P=0.18, r=0.36; P=0.29, r=0.28, respectively). There were no significant correlations between ΔFS and PACES immediately after and 20 min post across all HIIE conditions (all P>0.12; all r<0.32)

3.4 RPE responses The RPE responses during HIIE are illustrated in Figure 1D. RPE showed a significant condition by interval number interaction (P<0.01). RPE was significantly greater during $HIIE_{H-L}$ than $HIIE_{CON}$ and $HIIE_{L-H}$ at work-intervals 1 to 3 (all P<0.016; all ES at work interval 1 > 3.06; ES at work interval 3 > 1.26), but significantly lower than $HIIE_{CON}$ and $HIIE_{L-H}$ at work-intervals 6 to 8 (all P<0.014; all ES > 1.14).

3.5 Cerebral haemodynamics The cerebral haemodynamics (ΔO_2Hb, ΔHHb and TOI) during the HIIE protocols are illustrated in Figure 3. There was no condition by interval number interaction (P=0.78) or effect of condition (P=0.87), but there was a main effect of interval number (P<0.01) for cerebral ΔO_2Hb. Cerebral ΔO_2Hb increased from warm-up at work intervals 5 to 8 for all conditions (all P<0.042, all ES>0.39). There was a positive correlation between ΔO_2Hb and FS in $HIIE_{H-L}$ (P=0.034, r= 0.53), but negative correlation between ΔO_2Hb and FS in $HIIE_{CON}$ and $HIIE_{L-H}$ across the work intervals (all P<0.043; r= -0.62; r= -0.65, respectively). There was a significant positive correlation between the FS and ΔO_2Hb at work-interval 8 in all conditions (all P<0.034; all r>0.67).

Cerebral ΔHHb showed a significant condition by interval number interaction (P<0.01). Cerebral ΔHHb was significantly lower during $HIIE_{H-L}$ than $HIIE_{L-H}$ at work intervals 7 and 8 (all P<0.035; ES=0.68 to 0.84) and $HIIE_{CON}$ at work interval 8 (P=0.039; ES=0.40). Cerebral ΔHHb increased from warm-up to work interval 8 during $HIIE_{H-L}$ (all P<0.04; ES=0.86 to 0.62), $HIIE_{CON}$ (P<0.03; ES=0.84 to 1.48) and $HIIE_{L-H}$ (all P<0.002; ES= 0.48 to 2.07). However, during $HIIE_{H-L}$, no significant differences between work interval 1 and work intervals 7 to 8 were evident for cerebral ΔHHb (all P>0.58, all ES>0.22). There was a negative correlation between ΔHHb and FS responses across the work intervals in all conditions (all *P*<0.002; $HIIE_{H-L}$, *r*= -0.73; $HIIE_{CON}$, *r*= -0.84; $HIIE_{L-H}$, *r*= -0.81). There was a significant negative correlation between the FS and ΔHHb at work-interval 8 in all conditions (all *P*<0.014; all *r*>-0.60).

TOI showed a significant condition by interval number interaction (*P*=0.013). TOI was significantly greater during $HIIE_{H-L}$ than $HIIE_{L-H}$ at work intervals 7 to 8 (all *P*<0.011; ES= 0.79 to 0.98) and $HIIE_{CON}$ at work interval 8 (*P*=0.044; ES=0.38). TOI declined from warm-up at work intervals 5 to 8 during $HIIE_{L-H}$ (all *P*<0.02; ES=0.59 to 0.90) but increased from warm-up at work interval 8 (*P*=0.039; ES= 0.56) during $HIIE_{H-L}$. There was a positive correlation between TOI and FS responses across the work intervals in all condition (all *P*<0.001; $HIIE_{H-L}$, *r*= 0.92; $HIIE_{CON}$, *r*= 0.98; $HIIE_{L-H}$, *r*= 0.98). There was a significant positive correlation between the FS and TOI at work-interval 8 in all conditions (all *P*<0.024; all *r*>0.70).

4.0 DISCUSSION

This study presents novel data on affect, enjoyment and PFC haemodynamic responses during HIIE that consisted of increasing, decreasing, and constant delivery of the workload in adolescent boys and girls. The key findings from this study are: 1) $HIIE_{H-L}$ elicited lower positive affect and enjoyment during the initial work-intervals, but elicited greater positive affect and enjoyment during the later work intervals, compared to $HIIE_{L-H}$ and $HIIE_{CON}$; 2) similar enjoyment was observed for all HIIE conditions immediately after and 20 minutes after exercise; 3) similar cerebral $ΔO_2Hb$ was observed across conditions, but $HIIE_{H-L}$ elicited greater TOI in the presence of lower ΔHHb towards the end of the work intervals compared to $HIIE_{L-H}$ and $HIIE_{CON}$; 4) affect was strongly correlated with ΔHHb (negatively) and TOI (positively) during work intervals across all HIIE conditions.

In this study, we found a similar pattern of affect responses in the $HIIE_{CON}$ protocol to Malik et al. (2017b), who observed a decline in affect from baseline during the later stages of HIIE work intervals at 90% of maximal aerobic speed in adolescents boys. In contrast, affect responses only declined for the initial 75% of the total work performed during $HIIE_{H-L}$ (from baseline to work-interval 6) in the current study, resulting in more pleasurable feelings towards the end of work interval than $HIIE_{L-H}$ and $HIIE_{CON}$. Indeed, $HIIE_{H-L}$ fostered pleasurable feelings in all participants (100%) compared to 93% and 75% of participants in $HIIE_{CON}$ and $HIIE_{L-H}$, respectively, during the later HIIE work intervals. A similar pattern was observed by Zenko et al. (2016), who reported improved affect responses towards the end of continuous H-L (120–0% of the power output corresponding to the VT) compared to continuous L-H (0–120%) intensity exercise in healthy adults. It is important to note that all the prescribed HIIE conditions in our study were matched for total exercise duration (i.e. work and recovery) and external work, indicating that the observed changes in affect responses are due to the delivery pattern (e.g. increasing vs. decreasing) of the HIIE work intensity.

We observed greater PFC oxygenation (i.e. reflected by greater TOI in the presence of lower cerebral ΔHHb) during $HIIE_{H-L}$ compared to $HIIE_{L-H}$ and $HIIE_{CON}$ at the later stages of the work intervals, where the power output was 15% and 30% lower than $HIIE_{CON}$ and $HIIE_{L-H}$, respectively. The DMT predicts that the reduced positive affect during high-intensity exercise is caused by decreased activity in the PFC and a corresponding increased activity in the subcortical area driven by intensified interoceptive cues (Ekkekakis & Acevedo, 2006). A decrease in PFC activity is associated with reduced oxygen availability due to decreases in cerebral blood flow, meaning a greater increase in fractional oxygen utilisation is needed to meet metabolic demand. This observation typically occurs at exercise intensity above the respiratory compensation point (Bhambhani et al., 2007; Rooks et al., 2010) and can be indicated by a lower ΔO_2Hb and higher ΔHHb measured using NIRS (Ekkekakis & Acevedo, 2006; Tempest et al., 2014). Our data showed a significant difference in FS accompanied by a significant difference in TOI and ΔHHb but not in ΔO_2Hb across all HIIE conditions. These observations may suggest the potential link between FS with TOI and ΔHHb compared to ΔO_2Hb. Furthermore, the correlations between FS with TOI and ΔHHb showed a consistent pattern (positive and negative, respectively) across the HIIE conditions, whereas the correlations between FS and ΔO_2Hb exhibited an inconsistent pattern (positive correlation for ΔO_2Hb but negative correlation in both TOI and ΔHHb) across the conditions. We speculate, therefore, that increases in PFC oxygenation (greater TOI in the presence of lower cerebral ΔHHb) during the later stages of the $HIIE_{H-L}$ work intervals reflected better maintenance of the PFC activity levels compared to $HIIE_{L-H}$ and $HIIE_{CON}$, resulting in more pleasurable feelings. This potential mechanistic link is further supported via the significant correlation between affect with ΔO_2Hb (positive), TOI (positive) and ΔHHb (negative), respectively, at the end of work intervals in all HIIE conditions. Therefore, our findings show that the ability to increase PFC oxygenation to facilitate more pleasurable feelings at the end of HIIE work interval may be favourable via decreasing work intensity rather than maintaining or increasing the work intensity above the 85% peak power in youth.

We observed lower enjoyment during the earlier work intervals of $HIIE_{H-L}$ compared to $HIIE_{L-H}$ and $HIIE_{CON}$, but greater enjoyment during the later stages of $HIIE_{H-L}$ compared to $HIIE_{L-H}$. These differences in enjoyment responses between HIIE protocols may be related to the strong positive correlation between enjoyment and affective responses. In contrast, a previous study revealed similar levels of enjoyment across work intervals regardless of the intensity used (moderate vs. high) (Malik et al., 2018). Therefore, our findings extend previous HIIE work by supporting the proposition that H-L and L-H HIIE work intervals could influence enjoyment levels during HIIE.

Similar post-enjoyment (i.e. immediately and 20 min after exercise) was observed across all HIIE conditions, but only post-enjoyment in $HIIE_{H-L}$ and $HIIE_{CON}$ was positively correlated with affect at the end of HIIE. According to Fredrickson and Kahneman (1993), people tend to recall the peak and end affective responses and are therefore more likely to adhere to the behaviour if the ending is more pleasurable (Parfitt & Hughes, 2009). Moreover, Zenko and colleagues (2016) revealed that recovering of affect responses to more pleasant feelings near the end of exercise bout in H-L facilitates greater positive affective memories compared to L-H even after seven days of exercise. This shows that improvements in pleasurable feelings over time, during exercise, strongly influence retrospective evaluations of the exercise experience (Ariely & Zauberman, 2003; Zauberman, Diehl, & Ariely, 2006). Given that greater positive affect and enjoyment were found during work interval 8 in $HIIE_{H-L}$ compared to $HIIE_{L-H}$ and $HIIE_{CON}$ in this study, it seems plausible to suggest that the $HIIE_{H-L}$ protocol may be superior to the $HIIE_{CON}$ and $HIIE_{L-H}$ protocols in term of facilitating the adoption and maintenance of HIIE in adolescents when it comes to future exercise behaviour.

All the prescribed HIIE protocols elicited sufficient increases in HR ($\geq$90% HR_{max}) in the majority of our participants. It is therefore feasible that performing any of these protocols chronically, as opposed to acutely, could lead to physiological health benefits similar to those observed in other HIIE training studies in youth (Bond et al., 2017). Affect and enjoyment need to be considered, however, when designing an HIIE intervention to promote better implementation, maintenance and adoption of the exercise behaviour. As such, our findings suggest that the $HIIE_{H-L}$ and $HIIE_{CON}$ (which elicited pleasurable feelings in 100% and 93% of participants, respectively) prescribed in this study could provide an appropriate HIIE strategy for adolescents, but $HIIE_{H-L}$ could offer advancement to the $HIIE_{CON}$ protocol due to the improvement in pleasurable feelings and enjoyment responses. Although the $HIIE_{L-H}$ protocol generated positive affect responses in 75% of participants, this protocol elicited greater RPE than the other protocols, and the affect experienced was close to the boundary of the activated unpleasant feelings on the circumplex model (see Figure 2) due to high arousal (measured by FAS score). This indicates that $HIIE_{L-H}$ could develop feelings of distress and tension, which may potentially lead to exercise avoidant behaviours.

The strengths of this study are noteworthy. The partcipants in this study were insufficiently active and had low cardiorespiratory fitness which could augment the generalisability of our data for PA interventions that are substantially required in youth. Whilst many studies have prescribed HIIE based on the single and constant work intensity (Bond et al., 2017), the current study is the first to prescribe a HIIE protocol relative to decreasing (H-L) and incresing (L-H) delivery of the work intensity and its effect on perceptual (i.e. affect and enjoyment) and physiological responses (i.e. cerebral hemodynamics and HR). Our study also used a non-invasive NIRS technique to provide mechanistic insight into PFC activity in relation to affective responses during HIIE. To establish a more complete picture of the association between PFC haemodynamics and affective responses during HIIE, however, future studies may consider recording multiple areas of the PFC (e.g. the left and right lobe) as differential activation patterns associated with affective responses may occur within multiple areas of the PFC (Tempest et al., 2014). The present study is limited to exercise conducted in a laboratory, which is unlikely to reflect a participant's real-world affective response to exercise. It was necessary to conduct the research in a laboratory setting, however, as a lack of auditory, visual, and social interaction was required to ensure accurate comparison of perceptual (i.e. affect and enjoyment) cardiorespiratory factors (i.e. HR and $\dot{V}O_2$) across the HIIE conditions.

5.0 CONCLUSION

This study comprehensively extends previous work on the delivery pattern of HIIE work intervals (e.g. H-L and L-H) in adolescents and indicates that HIIE protocols with decreasing work intensity (i.e. H-L) could facilitate greater affective and enjoyment responses in youth. These observations indicate that HIIE may not entirely generate feelings of displeasure (Malik et al., 2018), and that the prescription and implementation depend on the type of protocol (e.g. decreasing, increasing, or constant) and work intensity used. Our data indicate that the decreasing pattern of $HIIE_{H-L}$ offers advancement to other HIIE protocols (i.e. $HIIE_{CON}$ and $HIIE_{L-H}$), by increasing positive affect and enjoyment responses towards the end of exercise. This observation supports the $HIIE_{H-L}$ protocol for fostering the adoption and maintenance of HIIE while facilitating health adaptations in youth. Finally, our study provides initial insight into role of PFC haemodynamics and affective responses in youth, showing that an increase in PFC oxygenation may facilitate the increases in positive affect experienced during HIIE.

Acknowledgements

We thank the staff and participants at Cranbrook Education School (Devon, UK) for their participation in this project. We would like to thank to Mr Sam Bailey and Mr Luke Connolly for their help with the technical support of the equipment. We also would like to thank Miss Kate Sansum for assistance with data collection.

Funding

Adam Abdul Malik is financial supported by the Government of Malaysia for the funding under the academic staff training scheme (USM/PPSP(Pent)/L2/bJld.XV).

Competing interest

The authors have no competing interest to disclose.

REFERENCES

Adegboye, A. R., Anderssen, S. A., Froberg, K., Sardinha, L. B., Heitmann, B. L., Steene-Johannessen, J., Andersen, L. B. (2011). Recommended aerobic fitness level for metabolic health in children and adolescents: a study of diagnostic accuracy. *Br J Sports Med, 45*(9), 722-728. doi:10.1136/bjsm.2009.068346.

Ariely, D., & Zauberman, G. (2003). Differential partitioning of extended experiences. *Organ Behav Hum Decis Process, 91*, 128-139. doi:10.1016/S0749-5978(03)00061-X

Barker, A. R., Williams, C. A., Jones, A. M., & Armstrong, N. (2011). Establishing maximal oxygen uptake in young people during a ramp cycle test to exhaustion. *Br J Sports Med, 45*(6), 498-503. doi:10.1136/bjsm.2009.063180

Benjamin, C. C., Rowlands, A., & Parfitt, G. (2012). Patterning of affective responses during a graded exercise test in children and adolescents. *Pediatr Exerc Sci, 24*(2), 275-288.

Bhambhani, Y., Malik, R., & Mookerjee, S. (2007). Cerebral oxygenation declines at exercise intensities above the respiratory compensation threshold. *Respir Physiol Neurobiol, 156*(2), 196-202. doi:10.1016/j.resp.2006.08.009

Biddle, S. J., & Batterham, A. M. (2015). High-intensity interval exercise training for public health: a big HIT or shall we HIT it on the head? *Int J Behav Nutr Phys Act, 12*(1), 95. doi:10.1186/s12966-015-0254-9

Bond, B., Weston, K. L., Williams, C. A., & Barker, A. R. (2017). Perspectives on high-intensity interval exercise for health promotion in children and adolescents. *Open Access J Sports Med, 8*.

Cohen, J. (1988). Statistical power analysis for the behavioural sciences. In. Lawrence Erlbaum, Hillsdale.

Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ, 320*(7244), 1240-1243.

Costigan, S. A., Eather, N., Plotnikoff, R. C., Taaffe, D. R., & Lubans, D. R. (2015). High-intensity interval training for improving health-related fitness in adolescents: a systematic review and meta-analysis. *Br J Sports Med, 49*, 1253-1261. doi:10.1136/bjsports-2014-094490

Duncan, A., Meek, J. H., Clemence, M., Elwell, C. E., Fallon, P., Tyszczuk, L., . . . Delpy, D. T. (1996). Measurement of Cranial Optical Path Length as a Function of Age Using Phase Resolved Near Infrared Spectroscopy. *Pediatr Res, 39*(5), 889-894.

Ekkekakis, P., & Acevedo, E. O. (2006). Affective responses to acute exercise: Toward a psychobiological dose-response model In E. O. Acevedo & P. Ekkekakis (Eds.), *Psychobiology of physical activity* (pp. 91-109): Champaign, IL: Human Kinetics.

Ekkekakis, P., Hall, E. E., & Petruzzello, S. J. (2005). Variation and homogeneity in affective responses to physical activity of varying intensities: an alternative perspective on dose-response based on evolutionary considerations. *J Sports Sci, 23*(5), 477-500. doi:10.1080/02640410400021492

Fredrickson, B. L., & Kahneman, D. (1993). Duration neglect in retrospective evaluations of affective episodes. *J Pers Soc Psychol, 65*(1), 45-55.

Ganesan, G., Leu, S.-y., Cerussi, A., Tromberg, B., Cooper, D. M., & Galassetti, P. (2016). Cerebral and Muscle Tissue Oxygenation During Incremental Cycling in Male Adolescents Measured by Time-Resolved NIRS. *Pediatr Exerc Sci, 28*(2), 275-285. doi:10.1123/pes.2015-0037

Hardy, C. J., & Rejeski, W. J. (1989). Not What, But How One Feels: The Measurement of Affect During Exercise. *J Sport Exer Psychol, 11*, 304–317.

Luszczyk, M., Kujach, S., Olek, R. A., Laskowski, R., & Szczesna-Kaczmarek, A. (2011). *Prefrontal Cortex Oxygenation and Muscle Oxygenation during Incremental Exercise in Children: A near-infrared spectroscopy study.* Paper presented at the Children and Exercise XXVII (Proceedings of the XXVII International Symposium of the European Group of Pediatric Work Physiology), Exeter, United Kingdom.

Malik, A. A., Williams, C. A., Bond, B., Weston, K. L., & Barker, A. R. (2017a). Acute cardiorespiratory, perceptual and enjoyment responses to high-intensity interval exercise in adolescents. *Eur J Sport Sci, 17*(10), 1335-1342. doi:10.1080/17461391.2017.1364300

Malik, A. A., Williams, C. A., Weston, K. L., & Barker, A. R. (2018). Perceptual Responses to High- and Moderate-Intensity Interval Exercise in Adolescents. *Med Sci Sports Exerc,* 50**,** 1021-1030.

Moore, S. A., McKay, H. A., Macdonald, H., Nettlefold, L., Baxter-Jones, A. D., Cameron, N., & Brasher, P. M. (2015). Enhancing a Somatic Maturity Prediction Model. *Med Sci Sports Exerc, 47*(8), 1755-1764. doi:10.1249/mss.0000000000000588

Motl, R. W., Dishman, R. K., Saunders, R., Dowda, M., Felton, G., & Pate, R. R. (2001). Measuring enjoyment of physical activity in adolescent girls. *Am J Prev Med, 21*(2), 110-117.

Parfitt, G., & Hughes, S. (2009). The Exercise Intensity–Affect Relationship: Evidence and Implications for Exercise Behavior. *J Exerc Sc Fit, 7*(2, Supplement), S34-S41. doi:http://dx.doi.org/10.1016/S1728-869X(09)60021-6

Phillips, L., Parfitt, G., & Rowlands, A. (2013). Calibration of the GENEA accelerometer for assessment of physical activity intensity in children. *J Sci Med Sport, 16*(2), 124-128.

Riddoch, C. J., Mattocks, C., Deere, K., Saunders, J., Kirkby, J., Tilling, K., . . . Ness, A. R. (2007). Objective measurement of levels and patterns of physical activity. *Arch Dis Child, 92*(11), 963-969. doi:10.1136/adc.2006.112136

Robertson, R. J., Goss, F. L., Boer, N. F., Peoples, J. A., Foreman, A. J., Dabayebeh, I. M., . . . Thompkins, T. (2000). Children's OMNI scale of perceived exertion: mixed gender and race validation. *Med Sci Sports Exerc, 32*(2), 452-458.

Rooks, C. R., Thom, N. J., McCully, K. K., & Dishman, R. K. (2010). Effects of incremental exercise on cerebral oxygenation measured by near-infrared spectroscopy: a systematic review. *Prog Neurobiol, 92*(2), 134-150. doi:10.1016/j.pneurobio.2010.06.002

Rose, E. A., & Parfitt, G. (2010). Pleasant for some and unpleasant for others: a protocol analysis of the cognitive factors that influence affective responses to exercise. *Int J Behav Nutr Phys Act, 7*, 15. doi:10.1186/1479-5868-7-15

Russell, J. A., Weiss, A., & Mendelsohn, G. A. (1989). Affect Grid: A single-item scale of pleasure and arousal. *J Pers Soc Psychol, 57*, 493–502.

Schneider, M., Dunn, A., & Cooper, D. (2009). Affect, exercise, and physical activity among healthy adolescents. *J Sport Exerc Psychol, 31*(6), 706-723.

Slaughter, M. H., Lohman, T. G., Boileau, R. A., Horswill, C. A., Stillman, R. J., Van Loan, M. D., & Bemben, D. A. (1988). Skinfold equations for estimation of body fatness in children and youth. *Hum Biol, 60*(5), 709-723.

Stanley, D. M., & Cumming, J. (2010). Are we having fun yet? Testing the effects of imagery use on the affective and enjoyment responses to acute moderate exercise. *Psycho Sport Exerc, 11*(6), 582-590. doi:10.1016/j.psychsport.2010.06.010

Stanley, D. M., Williams, S. E., & Cumming, J. (2009). Preliminary validation of a single-item measure of exercise enjoyment: The Exercise Enjoyment Scale. *J Sport Exerc Psychol, 31*, S138–S139.

Stych, K., & Parfitt, G. (2011). Exploring affective responses to different exercise intensities in low-active young adolescents. *J Sport Exerc Psychol, 33*(4), 548-568.

Svebak, S., & Murgatroyd, S. (1985). Metamotivational dominance: a multi-method validation of reversal theory constructs. *J Pers Soc Psychol, 48*, 107-116.

Taylor, K., Weston, M., & Batterham, A. (2015). Evaluating Intervention Fidelity: An Example from a High-Intensity Interval Training Study. *PLoS ONE, 10*, 4.

Tempest, G. D., Eston, R. G., & Parfitt, G. (2014). Prefrontal cortex haemodynamics and affective responses during exercise: a multi-channel near infrared spectroscopy study. *PLoS ONE, 9*(5), e95924. doi:10.1371/journal.pone.0095924

Zauberman, G., Diehl, K., & Ariely, D. (2006). Hedonic versus informational evaluations: task dependent preferences for sequences of outcomes. *J Behav Decis Mak, 19*(3), 191-211. doi:doi:10.1002/bdm.516

Zenko, Z., Ekkekakis, P., & Ariely, D. (2016). Can You Have Your Vigorous Exercise and Enjoy It Too? Ramping Intensity Down Increases Postexercise, Remembered, and Forecasted Pleasure. *J Sport Exerc Psychol, 38*(2), 149-159. doi:10.1123/jsep.2015-0286

Van Landuyt, L. M., Ekkekakis, P., Hall, E. E., & Petruzzello, S. J. (2000). Throwing the mountains into the lakes: On the perils of nomothetic conceptions of the exercise-affect relationship. *J Sport Exer Psychol, 22*(3), 208–234.

Table 1 Descriptive characteristics of the participants (N = 16)

	Boys (n=8)	Girls (n=8)	P- value	ES
Age (y)	12.4 ± 0.7	12.6 ± 0.8	0.49	0.27
Body mass (kg)	47.7 ± 6.9	47.8 ± 5.2	0.99	0.02
Stature (m)	1.56 ± 0.10	1.55 ± 0.09	0.82	0.11
BMI ($kg·m^{-2}$)	18.9 ± 2.2	19.1 ± 4.1	0.89	0.06
Body fat (%)	15.1 ± 3.9	23.0 ± 8.8	**0.04**	1.16
MPA per day (min)	37 ± 12	29 ± 13	0.20	0.64
VPA per day (min)	4 ± 2	3 ± 1	0.64	0.63
MVPA per day (min)	41 ± 16	32 ± 14	0.22	0.60

$\dot{V}O_2$ (L·min^{-1})	1.48 ± 0.21	1.46 ± 0.24	0.91	0.09
$\dot{V}O_{2max}$ (mL·min^{-1}·kg^{-1})	35.7 ± 3.8	33.2 ± 3.2	0.17	0.69
HR_{max} (bpm)	189 ± 7	186 ± 2	0.27	0.58
HR at VT (bpm)	150 ± 8	153 ± 9	0.17	0.53
VT (L·min^{-1})	0.75 ± 0.13	0.69 ± 0.13	0.38	0.46
VT (%$\dot{V}O_{2\,max}$)	49.8 ± 11.3	47.1 ± 7.4	0.58	0.28

Values are reported as mean ± standard deviation. Abbreviations: BMI, body mass index; MPA, moderate physical activity; VPA, vigorous physical activity; MVPA, moderate to vigorous physical activity; $\dot{V}O_{2max}$, maximal oxygen uptake; HR_{max}, maximal heart rate; %$\dot{V}O_{2max}$, percentage of maximal oxygen uptake; VT, ventilatory threshold.

Table 2 Cardiorespiratory responses to HIIE with different protocols

	$HIIE_{CON}$	$HIIE_{H\text{-}L}$	$HIIE_{L\text{-}H}$
Average HR (bpm)	155 ± 7	153 ± 5	152 ± 4
Average % HRmax	83 ± 4	82 ± 4	81 ± 3
Peak HR (bpm)	$179 \pm 4^{\#}$	$172 \pm 6^{\wedge *}$	$183 \pm 4^{\#}$
Peak %HRmax	$96 \pm 4^{\#}$	$92 \pm 4^{\wedge *}$	$97 \pm 1^{\#}$
Average $\dot{V}O_2$ (L·min^{-1})	0.92 ± 0.13	0.91 ± 0.14	0.90 ± 0.17
Average $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	63 ± 9	63 ± 10	62 ± 11
Peak $\dot{V}O_2$ (L·min^{-1})	1.23 ± 0.12	1.20 ± 0.15	1.23 ± 0.19

Peak $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	84 ± 11	81 ± 10	84 ± 11

Values are reported as mean ± standard deviation. Abbreviations: HR, heart rate; HR_{max}, maximal heart rate; $\dot{V}O_2$, oxygen uptake: $\dot{V}O_{2max}$, maximal oxygen uptake; %$\dot{V}O_{2max}$, percentage of maximal oxygen uptake; VT, ventilatory gas exchange.

[#]Significant difference between $HIIE_{H\text{-}L}$ ($P < 0.05$).

[^]Significant difference between $HIIE_{L\text{-}H}$ ($P < 0.05$).

*Significant difference between $HIIE_{CON}$ ($P < 0.05$).

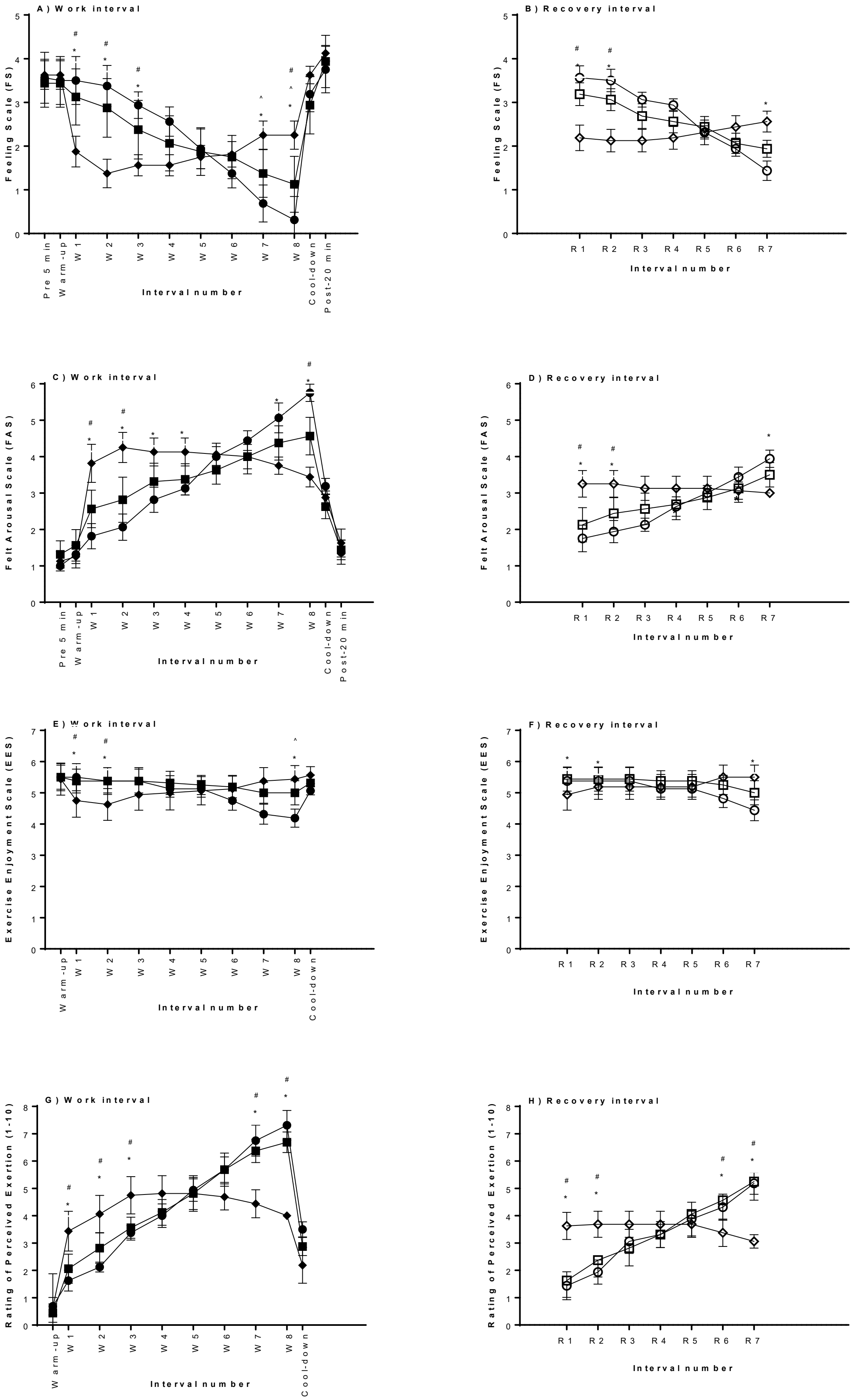
A) Work interval
Feeling Scale (FS)
Pre 5 min
Warm-up
W 1
W 2
W 3
W 4
W 5
W 6
W 7
W 8
Cool-down
Post-20 min
Interval number
B) Recovery interval
Feeling Scale (FS)
R 1
R 2
R 3
R 4
R 5
R 6
R 7
Interval number
C) Work interval
Felt Arousal Scale (FAS)
Interval number
D) Recovery interval
Felt Arousal Scale (FAS)
Interval number
E) Work interval
Exercise Enjoyment Scale (EES)
Interval number
F) Recovery interval
Exercise Enjoyment Scale (EES)
Interval number
G) Work interval
Rating of Perceived Exertion (1-10)
Interval number
H) Recovery interval
Rating of Perceived Exertion (1-10)
Interval number

Figure 1. Feeling scale (A and B), felt arousal scale (C and D), exercise enjoyment scale (E and F) and rating of perceived exertion (G and H) during the interval and recovery phases of HIIE protocols. $HIIE_{H\text{-}L}$ work interval (♦), $HIIE_{CON}$ work interval (■), and $HIIE_{L\text{-}H}$ work interval (●); $HIIE_{H\text{-}L}$ recovery interval (◊), $HIIE_{CON}$ recovery interval (□), and $HIIE_{L\text{-}H}$ recovery interval (○) Where, W= work interval and R= recovery interval. [#]Significant difference between $HIIE_{H\text{-}L}$ with $HIIE_{CON}$ ($P<0.01$). [^]Significant difference between $HIIE_{CON}$ with $HIIE_{L\text{-}H}$ ($P<0.01$). *Significant difference between $HIIE_{H\text{-}L}$ with $HIIE_{L\text{-}H}$ ($P<0.01$). Error bars are presented as SD. See text for details.

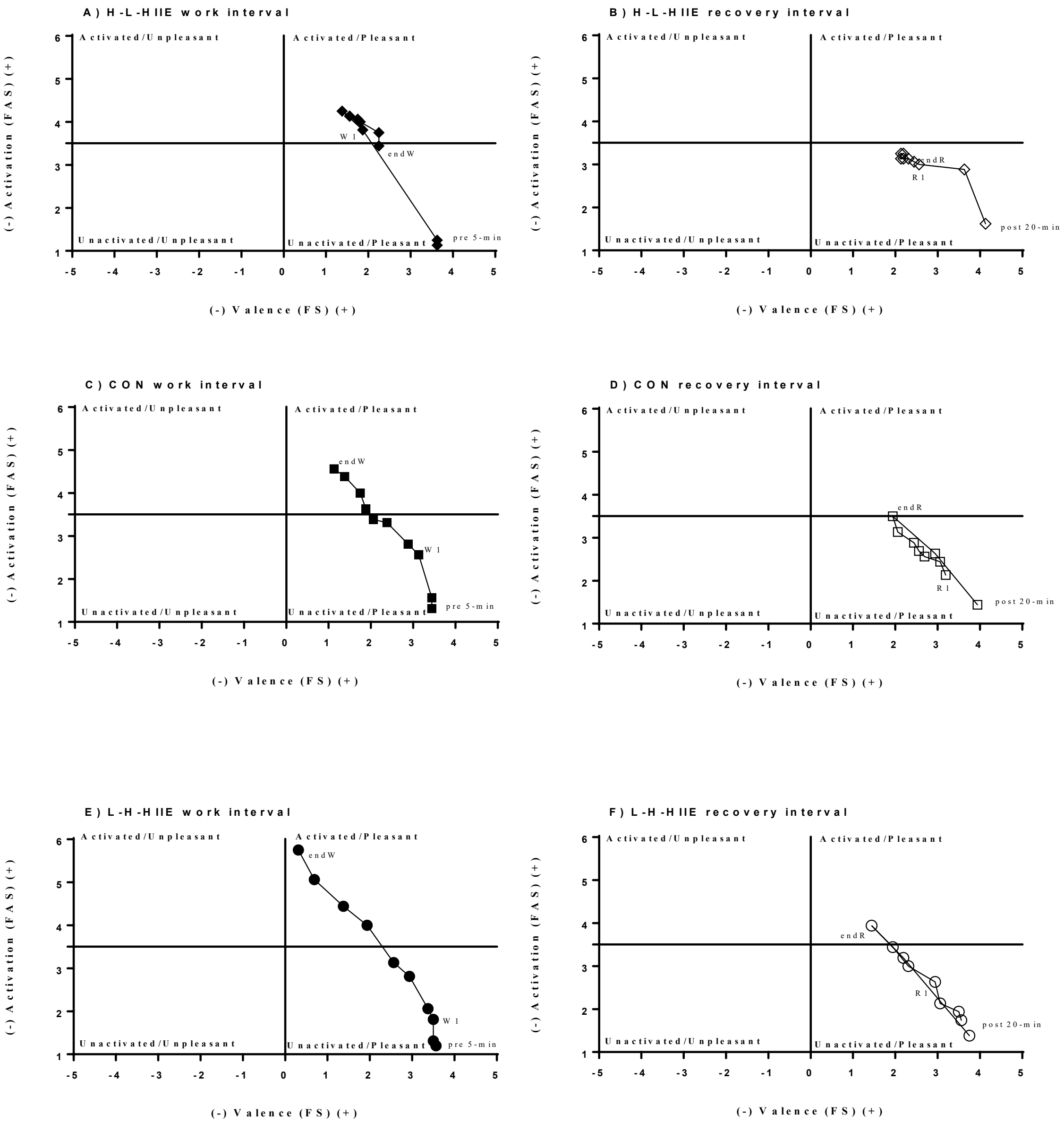

Figure 2. Valence (FS) and activation (FAS) during the work and recovery interval of $HIIE_{H-L}$ (A and B), $HIIE_{CON}$ (C and D) and $HIIE_{L-H}$ (E and F) plotted onto the circumplex model. Where, W= work interval, R= recovery interval, endW= work interval 8 in HIIE, and endR= recovery interval 7 in HIIE. Error bars are presented as SD. See text for details.

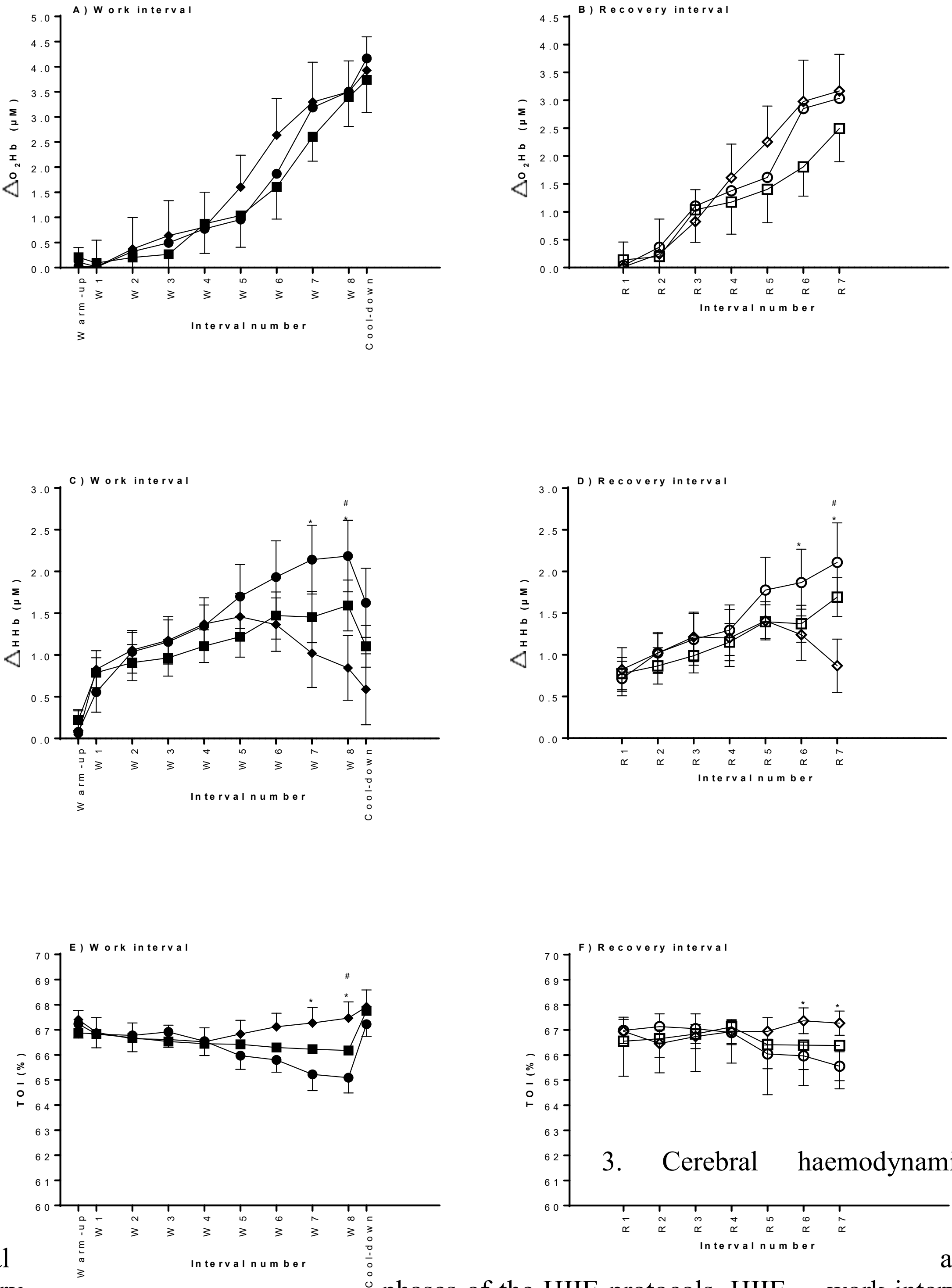

Figure 3. Cerebral haemodynamics during the interval and recovery phases of the HIIE protocols. $HIIE_{H-L}$ work interval (♦), $HIIE_{CON}$ work interval (■), and $HIIE_{L-H}$ work interval (●); $HIIE_{H-L}$ recovery interval (◊), $HIIE_{CON}$ recovery interval (□), and $HIIE_{L-H}$ recovery interval (○). Where, W= work interval and R= recovery interval. Where, W= work interval, R= recovery interval. #Significant difference between $HIIE_{H-L}$ with $HIIE_{CON}$ (P<0.05). ^Significant difference between $HIIE_{CON}$

with $\text{HIIE}_{\text{L-H}}$ ($P<0.05$). *Significant difference between $\text{HIIE}_{\text{H-L}}$ with $\text{HIIE}_{\text{L-H}}$ ($P<0.05$). Error bars are presented as SD. See text for details.